Journal of Forensic and Legal Medicine 19 (2012) 211–214

Contents lists available at SciVerse ScienceDirect

Journal of Forensic and Legal Medicine

journal homepage: www.elsevier.com/locate/jflm

Original communication

Multiplication factor versus regression analysis in stature estimation from hand and foot dimensions☆

Kewal Krishan MSc, PhD Sr. Assistant Professor [a,*], Tanuj Kanchan MD Associate Professor [b], Abhilasha Sharma MSc Former Student [a]

[a] Department of Anthropology, Panjab University, Sector-14, Chandigarh 160 014, India
[b] Department of Forensic Medicine, Kasturba Medical College, (Affiliated to Manipal University), Mangalore 575001, India

ARTICLE INFO

Article history:
Received 27 October 2011
Received in revised form
10 December 2011
Accepted 27 December 2011
Available online 21 January 2012

Keywords:
Forensic anthropology
Personal identification
Methods of stature estimation
Multiplication factor method
Regression analysis method

ABSTRACT

Estimation of stature is an important parameter in identification of human remains in forensic examinations. The present study is aimed to compare the reliability and accuracy of stature estimation and to demonstrate the variability in estimated stature and actual stature using multiplication factor and regression analysis methods. The study is based on a sample of 246 subjects (123 males and 123 females) from North India aged between 17 and 20 years. Four anthropometric measurements; hand length, hand breadth, foot length and foot breadth taken on the left side in each subject were included in the study. Stature was measured using standard anthropometric techniques. Multiplication factors were calculated and linear regression models were derived for estimation of stature from hand and foot dimensions. Derived multiplication factors and regression formula were applied to the hand and foot measurements in the study sample. The estimated stature from the multiplication factors and regression analysis was compared with the actual stature to find the error in estimated stature. The results indicate that the range of error in estimation of stature from regression analysis method is less than that of multiplication factor method thus, confirming that the regression analysis method is better than multiplication factor analysis in stature estimation.

1. Introduction

The use of anthropometry in the field of forensic science and medicine dates back to 1882 when Alphonse Bertillon, a French police expert invented a system of criminal identification based on anthropometric measurements. Since then, anthropometry has continuously been used in forensic examinations of unknown commingled human remains.[1,2] Anthropomtery helps in reconstruction of the biological profile of the deceased such as age, sex, ethnicity and stature.[3–5] Among these 'big fours' of forensic anthropology, estimation of stature is considered as one of the main parameter of personal identification in forensic examinations. In the past, many studies have been conducted on estimation of stature from various measurements on different parts of human body.[6–12]

There are two major methods of stature estimation in forensic investigations; the anatomical method and the mathematical method. The anatomical method, more commonly referred to as the "Fully method",[13] reconstructs stature by summing the measurements of the skeletal elements that contribute to height and adding a correction factor for the soft tissues. The mathematical method on the other hand is related to derivation of formulae that can be applied directly to estimate stature from a given bone/part of the body. The mathematical method makes use of the high linear correlation between the body parts and stature. One can utilize a regression equation that reflects the relationship between an individual's stature and the body part.[14] Further two more methods of stature estimation; FORDISC 3[15] and revised Fully method[16] were developed. The mathematical methods of stature estimation from bones or various body parts utilize two methods; regression analysis and multiplication factor (MF) method. Earlier studies have utilized either or both mathematical methods in estimation of stature.

Although some studies have stated that regression analysis method is more reliable than multiplication factor analysis[17–19]; none of the studies have demonstrated the extent of variability in estimated stature and actual stature using both the methods. The present study is an attempt to demonstrate the variability in estimated stature and actual stature using multiplication factor and regression analysis method.

☆ The paper is accepted for presentation at the 64th Annual Scientific Meeting of American Academy of Forensic Sciences (AAFS) to be held from February 20–25, 2012 at Atlanta, Georgia, USA.

* Corresponding author. Tel.: +91 172 2534230 (office), +91 9876048205 (mobile).
E-mail address: gargkk@yahoo.com (K. Krishan).

1752-928X/$ – see front matter © 2012 Elsevier Ltd and Faculty of Forensic and Legal Medicine. All rights reserved.
doi:10.1016/j.jflm.2011.12.024

2. Material and methods

2.1. Subjects

The present study consists of a cross-sectional sample of 246 subjects (123 males and 123 females) aged from 17 to 20 years. The subjects belong to a Rajput population of Himachal Pradesh State in North India. Rajput is an endogamous population and forms a major caste group of Himachal Pradesh State. This study is a part of a large study conducted on Rajputs of Himachal Pradesh and for comparing the common methods employed in stature estimation, utilizes the data used in previous studies.[20–22]

2.2. Anthropometric measurements

Four anthropometric measurements i.e. hand length (HL), hand breadth (HB), foot length (FL) and foot breadth (FB) were taken on the left side of each subject. All the measurements were taken in a well lighted room using standard anthropometric instruments in centimeters to the nearest millimeter according to the techniques described by Vallois.[23] The measurements were taken by one observer (AS) in order to avoid inter-observer error. All the landmarks and techniques for taking measurements are described in Krishan and Sharma[20] and Krishan et al.[22] The measurement error was also calculated and the procedure for calculation of measurement error was described in our earlier study.[22] Findings indicate that the technical error had a negligible contribution to the measurements and the measurements are reproducible without significant technical error.

2.3. Statistical analysis

The data obtained were computed and analyzed with SPSS (Statistical Package for Social Sciences, version 11.0) computer software. A multiplication factor for stature estimation was derived by dividing stature by hand and foot dimension in each individual. Mean of multiplication factor derived in each individual was taken as the multiplication factor for the study group. Male–female differences in the stature, hand and feet measurements and for the derived multiplication factors for estimation of stature were compared using Student's *t*-test. Level of significance was set at *p*-value less than 0.05. Regression formulae were derived for stature estimation from hand (HL, HB) and foot dimensions (FL, FB) in males and females, keeping stature as the dependent and each hand or foot dimension as an independent variable. Multiplication factors and regression equation thus derived for each variable were applied in the study group itself and the stature was estimated. Actual stature and the estimated stature from multiplication factor method as well as from regression analysis method were compared and the error of estimate was calculated by finding the difference between estimated and the actual stature (Error of Estimate = Estimated stature − Actual stature).

3. Results

Descriptive statistics for stature, hand and foot dimensions in males and females are shown in Table 1. Significant male–female differences were observed for the stature, hand and foot measurements ($p < 0.001$). Male dimensions were observed to be statistically larger than female. Descriptive statistics for the multiplication factors derived for the estimation of stature from hand and foot dimensions are shown in Table 2. Significant male–female differences were observed for the MF derived in the study ($p < 0.05$) except for the MF derived for HL that was almost similar in males and females ($p = 0.712$). Linear regression models derived for reconstruction of stature in males and females are shown in Table 3. Hand and foot measurements show a significant correlation with the stature in males and females ($p < 0.001$).

Table 1
Descriptive statistics of stature and hand and foot dimensions (cm) in males and females.

	Male ($n = 123$)			Female ($n = 123$)		
	Range	Mean	S.D.	Range	Mean	S.D.
Stature	147.6–183.6	168.2*	6.5	140.7–169.5	155.7*	5.2
HL	15.9–20.8	18.2*	0.9	15.1–19.2	16.8*	0.8
HB	07.1–09.8	8.1*	0.4	06.1–08.5	07.3*	0.4
FL	21.7–28.6	24.7*	1.2	20.4–24.9	22.6*	1.1
FB	08.1–10.9	9.5*	0.5	07.3–09.8	08.5*	0.5

HL – Hand Length, HB – Hand Breadth, FL – Foot Length, FB – Foot Breadth, S.D. – Standard Deviation, * – $p < 0.05$.

Actual stature and stature estimated from multiplication factor and regression analysis in males and females are compared in Table 4. Mean actual stature and stature derived from MF analysis and from regression analysis did not show any differences between them. However, it is evident that the range of stature estimated from MF analysis is broader and that from regression analysis is narrower than that of the actual stature. The standard deviation of estimated stature from the MF analysis exceeds the actual standard deviation of stature, whereas the estimates from regression analysis have standard deviations lower than the actual stature. It is apparent from the range of estimated stature using MF and regression analysis that the MF analysis overestimates the maximum actual stature whereas the regression analysis underestimates it. The minimum actual stature is mostly underestimated in MF analysis and overestimated in regression analysis. However when error of estimate was calculated, it is observed that with regard to the underestimation and overestimation of stature in the study group using multiplication factor and regression analysis, the error in estimating stature is significantly larger in multiplication factor analysis than that estimated from regression analysis. The maximum possible underestimation and overestimation of stature in the study group using multiplication factor and regression analysis is shown in Table 5.

4. Discussion

Stature estimation is an important factor in identification of commingled remains in forensic examinations. Of the two basic methods of estimating living stature from long bones and body parts i.e. anatomical and mathematical method,[24] the anatomic method is generally preferred over mathematical method when the complete skeleton or cadaver is available. The anatomical method involves the direct reconstruction of stature by measuring and adding together the lengths or heights of a series of contiguous skeletal elements from the skull through the foot. The development of the anatomical method is attributed to Fully's studies on stature estimation.[13] Many authors consider that the anatomical method

Table 2
Multiplication factors derived for stature estimation from hand and foot dimensions (cm) in males and females.

	MF- male ($n = 123$)			MF- female ($n = 123$)		
	Range	Mean	S.D.	Range	Mean	S.D.
HL	08.39–10.37	09.27	0.4	08.18–10.04	09.28	0.3
HB	17.93–24.06	20.82*	0.9	19.00–25.16	21.42*	1.2
FL	06.23–07.31	06.82*	0.2	06.37–07.43	06.89*	0.2
FB	15.10–20.69	17.73*	0.9	15.81–20.66	18.33*	0.9

MF– Multiplication Factor, HL – Hand Length, HB – Hand Breadth, FL – Foot Length, FB – Foot Breadth, S.D. – Standard Deviation, * – $p < 0.05$.

Table 3
Linear regression models derived for reconstruction of stature in males and females.

	Males ($n = 123$)	Females ($n = 123$)
HL	87.332 + 4.450 (HL*)	84.539 + 4.238 (HL*)
HB	102.110 + 8.169 (HB*)	120.414 + 4.843 (HB*)
FL	69.544 + 3.995 (FL*)	74.820 + 3.579 (FL*)
FB	124.336 + 4.616 (FB*)	111.232 + 5.224 (FB*)

HL – Hand Length, HB – Hand Breadth, FL – Foot Length, FB – Foot Breadth, *p-value < 0.001.

provides best approximation of stature when applicable to skeleton or cadaver.[24–30] To calculate the living stature of an individual using the anatomical method, correction factors that compensate for soft tissue also need to be added.[31,32] However, when mutilated remains and skeletal parts are referred for personal identification in forensic examinations, the forensic experts have to rely upon mathematical methods for stature estimation. Mathematical methods utilize the measurements of one or more bones or body parts to estimate stature. Thus a distinct advantage of mathematical methods is that a single body part can be used to estimate the living stature of an individual. The main disadvantage of the mathematical method however, is that the stature estimated using these methods is not absolutely accurate owing to wide variations in dimensions of body parts, bones and statute in a population group. Standard error of estimate thus needs to be considered giving a possible range of stature from a given bone/body part. More over, different formulae are required for different population groups, different bones or body parts.[33] Mathematical methods employed in stature estimation include multiplication factor and regression analysis. Forensic significance of these mathematical methods is based on the principle that there is a high linear correlation between an individual's stature and the body part or bone length.

Significant male–female differences in the stature, hand and foot measurements in the study have been demonstrated and discussed in our earlier studies.[20–22] Significant male–female differences were also observed for the multiplication factors derived for estimation of stature in the study. The sex differences in multiplication factors are attributed in general to the sex differences in male and female dimensions and stature. Linear regression models derived for reconstruction of stature in males and females represent a high degree of correlation between hand and foot measurements and the stature in males and females. On comparative analysis of actual stature and stature estimated from multiplication factor and regression analysis in males and females, it was observed that the mean actual stature, stature derived from MF analysis and from regression analysis did not show any differences between them. However, the range of stature estimated from MF analysis was broader than the actual stature while the range of stature estimated from regression analysis is narrower than that of the actual stature. The standard deviation of estimated stature from the MF analysis exceeds the actual standard deviation of stature, whereas the estimates from regression analysis have standard deviations lower than the actual stature. That itself suggests the limited utility of multiplication analysis in stature estimation. It is apparent from the range of estimated stature using MF and regression analysis that the MF analysis overestimates the maximum actual stature and underestimates the minimum actual stature whereas the regression analysis underestimates the maximum actual stature and overestimates the minimum actual stature. However, when error of estimate is calculated, the possibility of maximum underestimation and overestimation of stature is significantly larger in multiplication factor analysis than from the regression analysis.

Table 4
Actual stature versus stature estimated from multiplication factor and regression analysis in males and females.

	Male ($n = 123$)			Female ($n = 123$)		
	Range	Mean	S.D.	Range	Mean	S.D.
A Stature	147.6–183.6	168.2	6.5	140.7–169.5	155.7	5.2
MF Stature						
HL	147.5–192.9	168.5	8.5	140.1–178.1	155.8	7.7
HB	149.9–206.9	168.5	9.0	128.8–179.5	153.9	9.1
FL	148.8–196.1	168.4	8.3	139.9–170.7	154.9	7.3
FB	146.0–196.5	168.6	9.8	131.6–176.7	153.5	8.4
REG Stature						
HL	158.1–179.9	168.2	4.1	149.9–167.6	157.2	3.6
HB	160.1–182.2	168.2	3.5	149.9–161.6	155.7	2.1
FL	156.2–183.8	168.2	4.8	147.8–163.9	155.7	3.8
FB	161.7–174.7	168.2	2.5	149.4–162.4	155.7	2.4

A Stature– Actual Stature, MF Stature– Stature derived from multiplication factor analysis, REG Stature– Stature derived by regression analysis, HL – Hand Length, HB – Hand Breadth, FL – Foot Length, FB – Foot Breadth, S.D. – Standard Deviation.

Table 5
Error of estimate in stature estimation (estimated stature – actual stature) on application of multiplication factor and regression analysis in males and females.

Error of estimate	Male ($n = 123$)		Female ($n = 123$)	
	Maximum	Maximum	Minimum	Maximum
	Underestimation	Overestimation	Underestimation	Overestimation
MF analysis-				
HL	−19.44	15.63	−12.31	18.82
HB	−21.13	31.28	−25.83	16.75
FL	−09.92	17.99	−11.63	11.98
FB	−23.15	30.50	−19.98	19.75
Regression analysis-				
HL	−17.50	18.05	−06.91	18.28
HB	−13.68	14.96	−11.81	14.58
FL	−12.58	11.82	−08.36	07.89
FB	−15.50	15.34	−13.34	17.02

MF– Multiplication factor, HL – Hand Length, HB – Hand Breadth, FL – Foot Length, FB – Foot Breadth.

A multiplication factor in stature estimation is the ratio of the stature to the respective measurement of bone or body part. A mean multiplication factor thus calculated is used for estimating stature in forensic examinations. The multiplication factor method is a well known method and used frequently for stature estimation.[34] The usefulness of these methods is generally assessed on the basis of mean error (error of estimate). The error of estimate is usually large whenever the multiplication factor method is used. This may be attributed to the fact that this method utilizes the means values of stature and dimensions and does not take into consideration the range and variation in the data. In statistics, regression analysis is a measure of numerical relationship between variables that are correlated with each other. Thus, regression analysis is an approach to modeling the relationship between a scalar variable y and one or more variables denoted x. In linear regression, models of the unknown parameters are estimated from the data using linear functions. Such models are called "linear models". Linear regression model refers to an equation wherein if one variable is known, the other can be estimated.[35] In stature estimation by regression analysis method, stature remains the dependent variable and the long bone or a body part as independent variable. A regression equation thus derived reflects the relationship between the body part and stature. Trotter and Gleser[36,37] did pioneering work in this regard that is still considered as a groundbreaking study in the field.

Authors in the past have observed that regression analysis is a better method to estimate stature than multiplication factor method. Jasuja et al.[34] in their study observed a high mean error in the multiplication factor method and tried to evolve revised multiplication factors to reduce this error so that this method can be used more effectively with smaller error. Krishan[17,18] in his

studies on estimation of stature from foot, footprint and foot outline compared the two methods of stature estimation and observed that the reliability of stature estimation from regression analysis method was more than that of multiplication method. Sahni et al.[19] in their study on stature estimation also observed that the stature estimation was more reliable and accurate with regression analysis method than that of multiplication factor method. However, none of these studies prove this with evidence or show the extent of variability that exists in the estimated stature with these two methods.

5. Conclusion

In the present study, when error of estimate was calculated in stature estimation using different methods, it was observed that the minimum and maximum error in estimating stature in the study group is significantly larger in multiplication factor analysis than from the regression analysis. The results of the present study show that the extent of error of estimate inherent in estimation of stature by regression analysis is less than that of multiplication method. Hence, confirming that the stature estimation is more accurate and reliable with regression analysis method.

Conflict of interest

None declared.

Funding

Department of Anthropology (UGC Centre for Advanced Studies and FIST Department), Panjab University, Chandigarh, India.

Ethical approval

None declared.

Acknowledgements

The authors are thankful to the subjects who have voluntarily participated in the study. This study is a part of unpublished Master's dissertation submitted to the Department of Anthropology, Panjab University, Chandigarh, India. Thanks are also due to Department of Anthropology, Panjab University, Chandigarh, India for funding data collection and extending every possible help to conduct this research. The principal author is grateful to honorable Padamshree Professor R.C. Sobti, Vice-Chancellor, Panjab University, Chandigarh, India, for encouraging research and its publication in international journals of repute.

References

1. Krogman WM, Iscan MY. *The human skeleton in forensic medicine*. Springfield, IL: Charles C. Thomas; 1986.
2. Iscan MY. Rise of forensic anthropology. *Yearbook Phys Anthropol* 2008;**31**:203–30.
3. Iscan MY, Quatrehomme G. Medico-legal anthropology in France. *Forensic Sci Int* 1999;**100**:17–35.
4. Krishan K. Anthropometry in forensic medicine and forensic. Science – forensic anthropometry. *Internet J Forensic Sci*. Available at: www.ispub.com/ostia/index.php?xmlFilePath¼journals/ijfs/vol2n1/forensic.xml 2007;**2** [accessed 04.10.10].
5. Kanchan T, Krishan K. Anthropometry of hand in sex determination of dismembered remains – a review of literature. *J Forensic Leg Med* 2011;**18**:14–7.
6. Pelin C, Zağyapan R, Yazici C, Kürkçüoğlu A. Body height estimation from head and face dimensions: a different method. *J Forensic Sci* 2010;**55**:1326–30.
7. Krishan K, Kanchan T, DiMaggio JA. A study of limb asymmetry and its effect on estimation of stature in forensic case work. *Forensic Sci Int* 2010;**200**:181.e1–5.
8. Fawzy IA, Kamal NN. Stature and body weight estimation from various footprint measurements among Egyptian population. *J Forensic Sci* 2010;**55**:884–8.
9. Wilson RJ, Herrmann NP, Jantz LM. Evaluation of stature estimation from the database for forensic anthropology. *J Forensic Sci* 2010;**55**:684–9.
10. Kanchan T, Menezes RG, Moudgil R, Kaur R, Kotian MS, Garg RK. Stature estimation from foot length using universal regression formula in a North Indian population. *J Forensic Sci* 2010;**55**:163–6.
11. Cordeiro C, Muñoz-Barús JI, Wasterlain S, Cunha E, Vieira DN. Predicting adult stature from metatarsal length in a Portuguese population. *Forensic Sci Int* 2009;**193**:131e1–4.
12. Menezes RG, Kanchan T, Kumar GP, Rao PPJ, Lobo SW, Uysal S, et al. Stature estimation from the length of the sternum in South Indian males: a preliminary study. *J Forensic Leg Med* 2009;**16**:441–3.
13. Fully G. Une nouvelle méthode de détermination de la taille. *Ann Med Legale* 1956;**35**:266–73.
14. Brandt ET. Stature Wars: which stature estimation methods are Most applicable to Modern Populations? 2009, theses and dissertations – anthropology. Paper 18, Available at: http://ecommons.txstate.edu/anthroptad/18 [accessed 23.12.10].
15. Jantz R, Ousley S. *FORDISC 3.0 personal computer forensic discriminant functions*. Knoxville: University of Tennessee; 2005.
16. Raxter MH, Auerbach BM, Ruff CB. Revision of the fully technique for estimating statures. *Am J Phys Anthropol* 2006;**130**:374–84.
17. Krishan K. Estimation of stature from footprint and foot outline dimensions in Gujjars of North India. *Forensic Sci Int* 2008;**175**:93–101.
18. Krishan K. Determination of stature from foot and its segments in a north Indian population. *Am J Forensic Med Pathol* 2008;**29**:297–303.
19. Sahni D, Sanjeev, Sharma P, Kaur H, Aggarwal A. Estimation of stature from facial measurements in northwest Indians. *Leg Med* 2010;**12**:23–7.
20. Krishan K, Sharma A. Estimation of stature from dimensions of hands and feet in a north Indian population. *J Forensic Leg Med* 2007;**14**:327–32.
21. Kanchan T, Krishan K, Sharma A, Menezes RG. A study of correlation of hand and foot dimensions for personal identification in mass disasters. *Forensic Sci Int* 2010;**199**:112.e1–6.
22. Krishan K, Kanchan T, Sharma A. Sex determination from hand and foot dimensions in a North Indian population. *J Forensic Sci* 2011;**56**:453–9.
23. Vallois HV. Anthropometric techniques. *Curr Anthropol* 1965;**6**:127–44.
24. Lundy J. The mathematical versus anatomical methods of stature estimate from long bones. *Am J Forensic Med Pathol* 1985;**6**:73–5.
25. Olivier G. *Practical anthropology*. Springfield, IL: C.C. Thomas; 1969.
26. El Najjar MY, McWilliams KR. *Forensic anthropology: the structure, morphology, and variation of human bone and dentition*. Springfield, IL: Charles C. Thomas; 1978.
27. Stewart TD. *Essentials of forensic anthropology*. Springfield, IL: C.C. Thomas; 1979.
28. Lundy JK. A report on the use of Fully's anatomical method to estimate stature in military skeletal remains. *J Forensic Sci* 1988;**33**:534–9.
29. Ousley S. Should we estimate biological or forensic stature? *J Forensic Sci* 1995;**40**:768–73.
30. Maijanen H. Testing anatomical methods for stature estimation on individuals from the W. M. Bass donated skeletal collection. *J Forensic Sci* 2009;**54**:746–52.
31. Lundy JK. Living stature from long limb bones in the South African Negro. *S Afr J Sci* 1983;**79**:337–8.
32. Lundy JK. Revised equations for estimating living stature from the long bones of the South African Negro. *S Afr J Sci* 1987;**83**:54–5.
33. Dayal MR, Steyn M, Kuykendall KL. Stature estimation from bones of South African whites. *S Afr J Sci* 2008;**104**:124–8.
34. Jasuja OP, Singh J, Jain M. Estimation of stature from foot and shoe measurements by multiplication factors: a revised attempt. *Forensic Sci Int* 1991;**50**:203–15.
35. Sharma A. Bio-statistics: a brief overview. *J Karnat Medico-legal Soc* 2011;**20**:24–8.
36. Trotter M, Gleser G. Estimation of stature from long bones of American whites and Negroes. *Am J Phys Anthropol* 1952;**10**:469–514.
37. Trotter M, Gleser G. A re-evaluation of estimation of stature based on measurements taken during life and the long bones after death. *Am J Phys Anthropol* 1958;**16**:79–123.